

## SINGULARITY ANALYSIS OF KUKA 6 DOF ROBOT FOR MOTION SIMULATION

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### ABSTRACT

*Robot Singularity is a Point in work envelope, where the Robot loses its ability to move in some direction, and therefore, in simulation automatically selects and takes a path that is different. So the user has to adjust the Robot base or Target frame or re input the Points or path for robot. In this paper, analysis has been made to identify Robot singular points by Inverse Kinematics using Robotics-Tool box plug-in for MATLAB, and Jacobian Matrix method is also used to check singularity.*

**KEYWORDS:** Robot, Inverse Kinematics & MATLAB

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### 1. INTRODUCTION

The purpose of this paper is to derive Inverse kinematics based derivations of Singularity for KUKA KR5 Arc Robot, which is a 6-Degree of freedom Serial robot. Using the knowledge of the D-H parameters, Inverse kinematics approach is used to and obtained array of Joint angles for given end effector (EE) pose. By doing forward kinematic analysis on the array of Joint angles, the original poses were not obtained wherever the Input poses were singular. Same was verified by error value in Inverse kinematics itself. Hence, those poses were termed as kinematic singularities.

In the motion planning and execution of Serial robots, avoiding singularities is very significant. At the singular points, mobility of robot is lost in some direction and end effectors' arbitrary movement is impossible with some Desired Aspects [12-13].

In the current paper, KUKA KR5 Arc Robot Arm is presented first with joints and links. Thereafter, the D-H parameters are taken and joint limits specified. The work volume is presented in the Figure. Later, the Jacobian matrices were found out from Joint configurations and singularity points were obtained, if their determinants became zero.

### 2. THEORY

A point being out of reach is sometimes referred to as a singularity, the only way to test for that is failure of IK. A kinematic singularity happens when the determinant of the Jacobian matrix becomes zero. Kinematic analysis of serial robots is elaborately presented [1]. Analysis for the envelope singularities for X, Y, Z-axes manipulator positions is given in [2]. The D-H parameters, the Jacobian computation procedure with systematic, generalized method are used to derive the Jacobian matrix as discussed in [3]. H.Y.K. Lau and L.C.C. Wai [4]

studied the redundant control strategy of WAM having 7 dof. General 6 dof sing. There are many other important contributions regarding general 6R singularities of robots are studied in [5, 6]. Industrial models operating manuals give application knowledge of the singularity concepts [7, 8, and 9]. Denavit-Hartenberg Methodology of Co-ordinate frame referencing is given in [10]. Path tracing by Inverse Jacobian Method is discussed in [11].

### 3. SOFTWARE

We used KUKAKR5 Arc Robot model to carry out the work. A program is written in MATLAB with Robotic Toolbox plug-in. The Robotic Toolbox provides many functions for the study and simulation of classical serial link manipulators such as kinematics, dynamics, and trajectory generation. It contains functions and classes to represent orientation and pose in 2D and 3D. By using robotic tool box plug-in to MATLAB, robot virtual objects may be created by the experts to serial-link manipulator.

RoboAnalyzer is used to simulate the results obtained from the MATLAB program. Robo Analyzer is software that is based on 3D model and used to apply robotic concepts. It has features like representation of serial manipulators with revolute and prismatic joints, input of DH parameters, DH parameters based 3D model output, FK and IK, simulation with EE trace, plotting of graphs etc.,

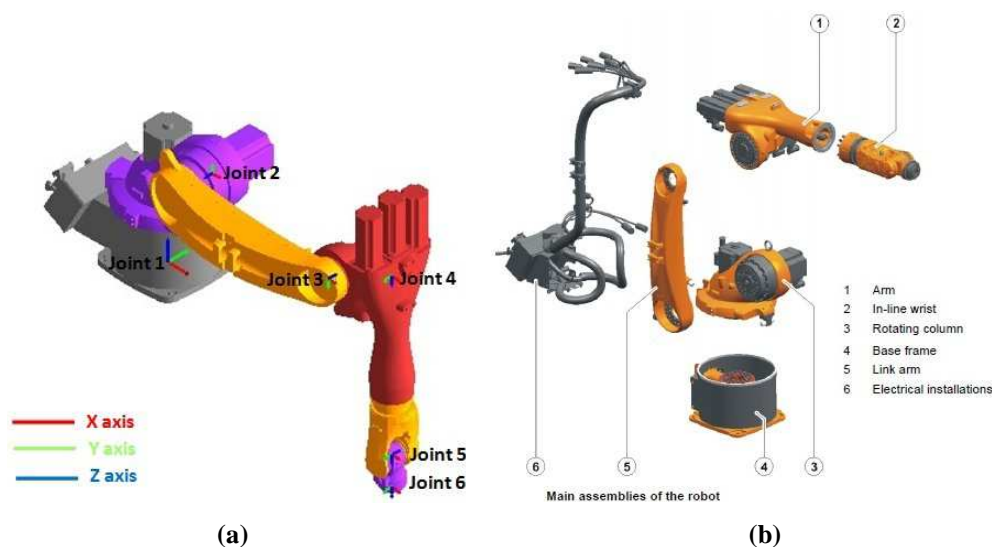


Figure 1: Kuka Kr5 Arc Robot (a) 6 revolute joints corresponding to 6 degrees of freedom.  
(b) Main assemblies of the robot (courtesy KUKA KR5 arc specification)

While the Robotic Toolbox uses radians for angles and Robo Analyzer uses degrees, conversions were made wherever required. The D-H parameters, initial joint angles, EE pose are given below.

Table1: KUKA KR5 Arc Robot's Denavit-Hartenberg (D-H) Parameters

Joint No	Joint Type	Joint Offset (b) meters	Joint Angle (theta) deg	Link Length (a) meters	Twist Angle (alpha) deg	Initial Value (JV) deg	Final Value (JV) deg
1	Revolute	0.4	Variable	0.18	90	0	0
2	Revolute	0.135	Variable	0.6	180	0	0
3	Revolute	0.135	Variable	0.12	-90	0	0
4	Revolute	0.62	Variable	0	90	0	0
5	Revolute	0	Variable	0	-90	0	0
6	Revolute	0.115	Variable	0	0	0	0

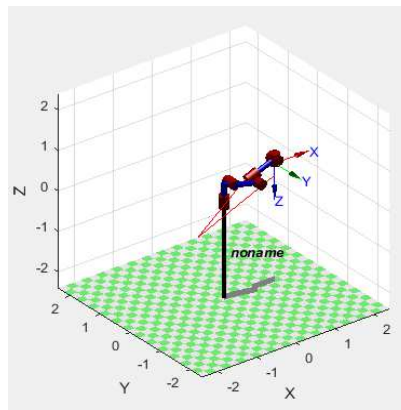
## 4. IMPLEMENTATION

### Case 1

A simple example to start with is presented below, figure2 shows expected path to be traced by the KUKA KR5 Arc Robot. When the co-ordinate points are singular, it results in a figure other than expected as shown in figure 3.



**Figure 2: Expected Path**



**Figure 3: Output of Expected Path Traces (Figure 2)**

### Case 2

When the figure like rectangle is required to be traced, it plots rhombus like figure if the co-ordinate points are singular. This has been tried in MATLAB and when XY plane rectangle is attempted, it traces rhombus like figure due to singularity as shown, (figure 3). The code to trace rectangle path original is given below.

### Code

```
%robotic Tool-box startup command

startup_rvc

% D-H parameters

% %L = Link ( [Th d a alph] 'Link' );

L(1) = Link ( [ 0.4.18 pi/2] );

L(2) = Link ( [ 0.135.6 pi ] );

L(3) = Link ( [ 0.135.12 -pi/2 ] );

L(4) = Link ( [ 0.62 0 pi/2 ] );

L(5) = Link ( [ 0 0 0 -pi/2 ] );

L(6) = Link ( [ 0.115 0 0 ] );
```

```

Rob = SerialLink (L);

A= cat(3, [1 0 0 1.2; 0 -1 0 0.5; 0 0 -1.2; 0 0 0 1], [ 1 0 0 2.7; 0 -1 0 0.5; 0 0 -1.2; 0 0 0 1],[ 1 0 0 2.7; 0 -1 0 1.3; 0
0 -1.2; 0 0 0 1], [ 1 0 0 1.2; 0 -1 0 1.3; 0 0 -1.2; 0 0 0 1], [ 1 0 0 1.2; 0 -1 0 0.5; 0 0 -1.2; 0 0 0 1]);

q1=Rob.ikcon(A);

Rob.plot(q1,'trail','r');

```

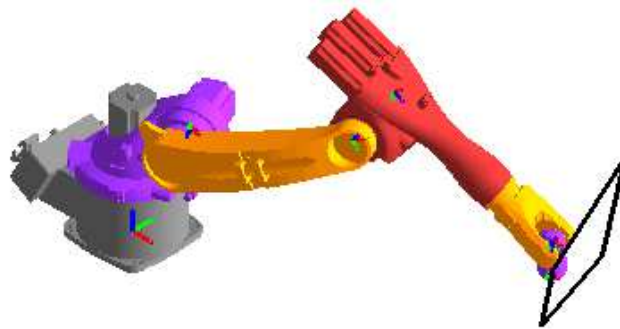


Figure 4: Output of Rectangular Path

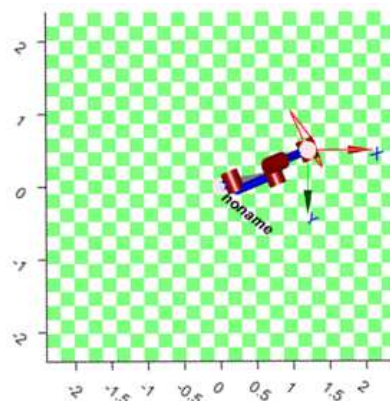


Figure 5: Output in Matlab of Rectangular Path

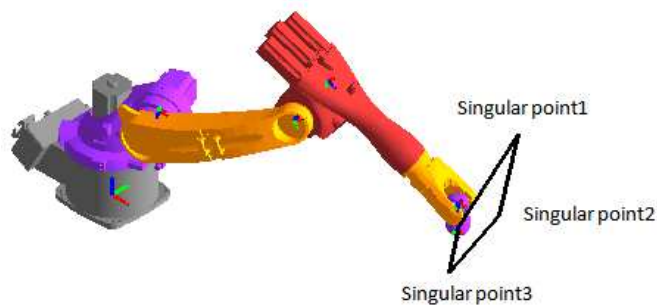


Figure 6: Singular Points in Case 2

## 5. INFERENCE

In case 2, the actual fk parameters is given below. It can be seen from Err that Initial point error is 0 and 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup> points have errors and last point of the rectangle(same as starting point) has 0 error.

**Check**

```
>> Rob.fkine(q1)
```

**Results of the Above Command**

ans(1)	1.0000 -0.0001 0.0001 1.2 -0.0001 -1.0000 -0.0001 0.5 0.0001 0.0001 -1.0000 0.2 0 0 0 1
ans(2)	0.9922 0.0014 0.1250 1.402 -0.0015 -0.9997 0.0231 0.2596 0.1250 -0.0231 -0.9919 0.2444 0 0 0 1
ans(3)	0.9908 0.0046 0.1354 1.287 -0.0043 -0.9979 0.0652 0.6196 0.1354 -0.0652 -0.9886 0.2483 0 0 0 1
ans(4)	0.9997 0.0003 0.0233 0.9589 -0.0003 -0.9997 0.0253 1.039 0.0233 -0.0253 -0.9994 0.2192 0 0 0 1
ans(5)	1.0000 -0.0001 0.0001 1.2 -0.0001 -1.0000 -0.0000 0.5 0.0001 0.0000 -1.0000 0.2 0 0 0 1

**Solution Error Commands**

```
>> [q1,err]=Rob.ikcon(A);
```

```
>> err
```

**Output of the Above Command**

Err	0.0000 2.9895 4.2166 0.2171 0.0000
-----	--

As seen from err, it is clear that there is a problem with reachability of points 2, 3, 4.

**Jacobian Test**

j=Rob.jacob0(q1, 'rpy') has given Jacobian matrix zero or error as not reachable for 2<sup>nd</sup> 3<sup>rd</sup> and 4<sup>th</sup> co-ordinate points' corresponding joint angles. Jacobian matrix being zero is indicative of the fact that Robot end effectors expected position is singular.

## 6. CONCLUSIONS

Robot path planning carried out path planning by this analysis in Robotics Toolbox. The error coming non zero is indicative of Singularities. So, the points can be altered or readjusted with reference to the Global co-ordinates. Also Jacobian at each configuration of the robot being non zero is a second test.

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